8244 WO

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) Internati nal Patent Classification 5 : H02M 3/22

A1

(11) International Publication Number: WO 91/078

(43) International Publication Date: 30 May 1991 (30.05.

WO91/07807

(21) International Application Number: PCT/SE90/00710

(22) International Filing Date: 2 November 1990 (02.11.90)

(30) Priority data: 8903883-0 20 November 1989 (20.11.89) SE

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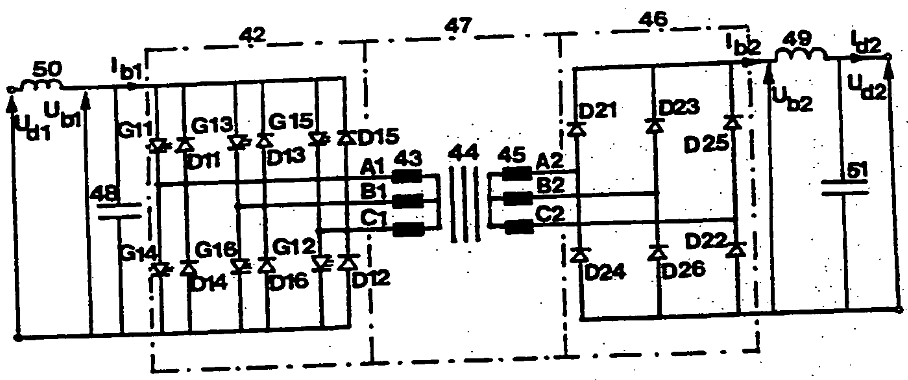
(81) Designated States: AT (European patent), BE (European patent), BR, CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US.

Published
With international search report.
In English translation (filed in Swedish).

(54) Title: DC/DC POWER TRANSFORMER



(57) Abstract

The DC/DC power transformer is an arrangement for direct transformation of high electric powers from one DC volta level to another DC voltage level without intermediate AC voltage network. The DC voltage is today basically used for tran mission of high electric powers at long distances. The DC voltage levels for these transmissions are normally high. The DC/D power transformer allows several DC voltage levels to be used in one and the same DC voltage network. The principle for th arrangement is that the valve windings (43, 45) from one or several converter transformers (47) are connected to two val bridges, which generate opposing cyclically variating magnetic fl ws in the transformer cores (44). One of the valve bridges is o erated as an inverter (49) and the other as a rectifier (46) and in this manner the power is transformed from one DC voltage lev (U_{d1}) to another (U_{d2}). At the high voltage levels f r which the invention is intended the leakage inductances in the transfo mers will be high as a consequence of the insulation levels and due t this special arrangements must be made in order commutate the magnetic energy from one phase of the transf rmer to another with ut creating great losses. The arrang ment is proposed in a line commutated alternative (figure 5) and in a selfcommutated alternative (figure 4). The first utiliz a third AC voltage reference winding (A3, B3, C3 in figure 5) for this commutation. In the second alternative an extern over the bridge connected capacitor (48 in figure 4) is utilized for this commutation purpose. Both alternatives may be d signed galvanically insulated or in autocoupling (figure 10).

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DC/DC POWER TRANSFORMER

FIELD OF THE INVENTION

This invention relates to an arrangement for direct transformation of electric power from one DC-(=direct current) voltage to another DC-voltage.

BACKGROUND OF THE INVENTION

In power transmission DC-voltage is used to transmit high electric powers from production centers to consumtion centers. Since the power is generated and distributed with AC networks (1,2) it is necessary to transform the AC-voltage to a DC-voltage (U_d in fig. 1) by means of a rectifier (3) and on the other end re-transform the DC-voltage to an AC-voltage by means of an alternator (4). These convertors are composed of converter transformers (5,6) and valves (7) which are connected into valve bridges (8,9). The rectifier and the inverter as well as the valvebridges are known and described in reference 1, chapter 2 and 3. The rectifier and the inventer can be provided with filters on the AC-voltage side (10, 11) as well as on the DC-voltage side (12, 13). These filters as well as the smoothing reactor (14, 15) on the DC-voltage side are provided in order to filter harmonics in current and voltage, which are generated as a consequence of the transformation from AC- to DC-voltage and vice versa. Each rectifier or inverter consequently needs a lot of equipment which also generates a lot of losses. This has strongly restricted the utilization of High Voltage Direct Current as means of transmitting electric power.

THE STANDPOINT OF TECHNOLOGY

With technology known today transformation of electric power from one high voltage DC-voltage level to another high voltage DC-voltage level, the power is by means of an alternator converted to an AC-voltage and then by means of a rectifier converted to the other DC-voltage level. Another known arrangement is serieconnection of a couple of converters for increasing or decreasing of the DC-voltage level in proportion to the power supplied to or withdrawn from the AC-voltage network (compare reference 2).

Known arrangements of DC/DC transformation for low voltage application (se e.g. chapter 7 in reference 3) are not suitable for power transmission and high voltage equipment, due to high requirement on low noise interference, low losses and high insulation levels and the high leakage inductances in the transformers related to the high v ltage levels.

The known rectifier (3) and inverter (4) are drawn in fig. 1. In the figure a 12-puls configuration is illustrated with star- and delta-connected converter transformers, which is the most common configuration today. This known configuration and corresponding firing sequence is described in chapter 2.9 of reference 1. In the 12-pulse configuration the firing varies cyclically from one valve to another in each 12-pulse group (8, 9). The two series connected 6-pulse groups in each of the rectifier and the inverter are phase shifted 30° since the transformer valve windings in the upper group are star connected (16, 18) and in the lower delta connected (17, 19). Due to restrictions in maximum power handling capacity of each transformer unit the transformer windings may be divided in one, two, three or six units. In each of these units there must be at least one AC-winding (20, 21) with the same phase shift as the valve windings in the respective transformer unit. The greatest quantity of transformer units and lowest power handling capacity per unit is achieved if only one valve winding and corresponding AC winding is placed in one and the same transformer unit.

Since rectifying and inversion with today's power technology in performed with line commutated valves, the firing and extinction is achieved only with certain firing angle, α, and extinction angle, γ, respectively. Commutation from the valve winding of one phase, to a valve winding of another phase will due to the transformer leakage inductance only be achieved with a certain overlap angle, u. Due to these a certain phase shift between the voltage and the current is created during the rectification and the inversion processes. This implies in a deficit of reactive power as described in reference 2. In order to compensate for this it has become useful to provide the convertors not only with ac-filters (10, 11) but also with shunt capacitor banks (22, 23) for generation of reactive power. The DC-current control is an essential function of the known DC-transmission. The line direct current (I_d in fig. 1) in the known DC voltagetransmission is controlled by the DC voltages in the converter stations through the formula:

$$I_d = \frac{U_d^R - U_d^2}{R}$$

I_d = Line DC-current

U_d^R = DC-voltage in rectifier

U_d^I = DC-voltage in inverter

R = Line resistance

The DC-voltages are controlled by the firing and extinction angles and the tap changers in the way described in chapter 7 of reference 4.

AIM AND PRINCIPLE CHARACTERISTICS OF THE INVENTION

This invention describes an arrangement and related couplings for direct transformation of electric power from one DC voltage to another. The arrangement is composed of an inverter bridge (24), converter transformers (25) and a rectifier bridge (26), in which the firing sequence of the valves (27) is adjusted, so that both bridges generates variating electromagnetic fields of opposing polarity in the transformer cores with related windings (25).

If the converter transformers in the known converters are provided with two galvanically isolated valve windings (28 resp. 29, 30 resp. 31), n all phases, where the known arrangement only has one valve winding (16, 18, 17, 19) these valve windings can be connected to two independent bridges (24 resp 26). These independent valve bridges can now follow two different cyclic firing sequencies. By arranging the phase shift between the valve windings from the two bridges, opposing magnetic field can be created in the core(s) of the converter transformer(s) (32, 33). By in this manner driving one of the valve bridges as an inverter (25) and the other valve bridge as a rectifier (26), power can be transformed from one DC-voltage level (U_{d1}) to another (U_{d2}). The relation in voltage and current is thus determined by the turns ratio in the two valve windings from the two valve bridges. If line commutated valves are used the firing and extinction must be achieved with certain delay angles in relation to an AC reference voltage winding. An AC voltage winding (34, 35) can be connected to each phase and transformer unit for this purpose. This winding is connected to an AC voltage reference n t (36), with ne busbar per phase.

The aim of this AC-voltage reference net is to form a voltage reference against which the delay angles of the rectifier and inverter bridges

are referred. Sufficient power for the AC voltage reference may be externally generated or supplied by a three phase synchronous generator (37). The synchronous generator may also by itself or in parallel with shunt capacitor banks (38) provide reactive power corresponding to the reactive power consumtion of the line commutated DC/DC power transformer due to the delay angles. AC-filters (39) may also be connected to the reference net in order to take care of current harmonics generated during the rectification and inversion processes.

THE PRINCIPLE OF THE INVENTION

The principle of the known bridge coupling is that an AC voltage connected to a transformer core will provide a cyclically variating magnetic field. This variating magnetic field generates, through the turns ratio, voltages in the other windings connected to the same core. The cyclic firing sequence in the valve bridges (8, 9) will result in DC voltages with a certain ripple over the valve bridges. The smoothing reactors (14, 15) inhibit this voltage ripple to pass on to the DC lines. When the coupling is provided with a load, current is withdrawn. The current is transformed over the transformer core according to the principle of ampere turns ratio balance. This process is more detaily explained in chapter 3 of reference 1.

The principle of the invention described herein is that the valve windings of the inverter bridge (24), through its cyclic firing sequence in the same manner as the known inverter may generate a cyclically variating magnetic field in respective transformer core (32, 33). By means of a co-variating cyclic firing sequence in the rectifier bridge (26) the thus induced voltages will build up a DC voltage (U_{d2}) over the rectifier bridge, with generates an opposing magnetic field in the core. When the rectifier bridge is provided with a load, current will de transformed according to the principle of ampere turns ratio balance between primary and secondary windings of a transformer.

It self commutated valves are utilized, no further windings are needed, since the cyclic sequence with forced commutation will lead to that currents are commutated from one phase to another according to a predetermined frequency.

A self commutated inverter for conversion of high voltage DC to three phase AC is known and described in chapt r 6.1 of r f rence 3. In figure 6.1 of this reference the inverter is shown. Such a bridge coupling may be used as inverter bridge (42) in a self commutated DC/DC

pow r transformer as illustrated in figur 4. In th known bridge coupling two pposing thyristors are always on. In the bridge coupling described here, on the contrary, only one thyristor in each three pulse group shall be on at the same time. Through the cyclic firing and extinction sequence of the thyristors (G11-G16):
G11 ⇒ G12 ⇒ G13 ⇒ G14 ⇒ G15 ⇒ G11 ⇒ .... a variating electromagnetic field is generating by the valve windings (43) in the transformer windings and its core (44). The diode valves (D11-D16) commutates the current when an opposite valve has extinguished. When for example the thyristor valve G11 extinguishes the current will due to the transformer leakage inductance continue through winding A1. The voltage in the blocked direction of the thyristor valve will therefore rapidly raise until the diode valve D14 starts to conduct. A commutating voltage has been built up which commutates the current through the winding. The valve windings (43) from such an inverter (42) may be winded on the same transformer core (44) as the valve windings (45) connected to a rectifier (46) built up of diode valves (D21-D26). The inverter in the above described manner generates an electromagnetic field, which induces voltages in the valve windings (45) of the rectifier. By means of the diode valves (D21-D26) in the bridge coupling (46) these voltages are rectified.
The firing and extinction sequence of the inverter is designed so that the thyristor valves (G11-G16) will be extinguished and fired in a cyclic sequence, as shown in figure 3, where:

T - Time of a cycle
F - Firing signal
E - Extinction signal
u_T - Overlap $= \frac{u}{360} \cdot T$ (p.u.)
U_{A1}, U_{B1}, U_{C1} - Phase voltages in inverter valve windings (p.u.)
U_{A2}, U_{B2}, U_{C2} - Phase voltages in rectifier valve windings (p.u.)
U_A, U_B, U_C - Phase currents (p.u.)

Two valves connected to different transformer windings are always on, e.g. in time interval $(0 - \frac{T}{6})$ the G11 connected to A1 and the G16 connected to B1 are on. The voltage over the inverter bridge (U_{b1}) will distribute uniformly over these windings. If we first regard the interval utside the commutation, i.e. $(u_T - \frac{T}{6})$, the whol DC current will flow through both valve windings A1 and B1 and be transformed by ampere turns rati balance to valve windings A2 and B2 respectively.

Since positive voltage is created in the connection point of A2 and currents flows in this direction, the diode valve D21 will c nduct in the forward direction. The diode valve D26 will conduct current into valve winding B2 from negative polarity. A positive voltage (U_{b2}) is thus created over the rectifier bridge. The commutation process for the self commutated DC/DC power transformer is most easily described by an example. We regard the interval ($\frac{T}{6}$, $\frac{T}{6}$ + u_T) when the current is commutated from thyristor valve G16 to thyristor valve G12. G16 is ordered to extinguish and a firing signal is emitted to valve G12.The valve windings B1 and B2 will continue to conduct current in the same direction as before due to the leakage inductance of the transformer. The voltage over valve G16 will therefore increase rapidly in the blocking direction, until the diode (D13) of the opposite valve starts to conduct.

Then a voltage is built up over the valve winding opposing the current flowing through it. This voltage will de-commutate the current through the winding. At the same time the positive voltage over valve winding C1 will increase the current through this winding with a current derivative determined by the relation between applied commutating voltage and the transformer leakage inductance. When the entire current has commutated over from B1 to C1 the diode valve D13 extinguishes. Since the current extinction of the bridge current (I_{b1}) happens almost momentarily, while the current increase is gradual, a sawtand formed ripple is created in the bridge current of the inverter (I_{b1} of figure 3). The same current changes which has occurred on the inverter valve winding will due to the ampere turns balance also occur in corresponding windings in the rectifier. Here the current only commutates between valves in the same direction. The bridge current in the rectifier (I_{b2}) will therefore not present a corresponding ripple.

During the commutation process, the commutating voltages are not transferred to the rectifier bridge. A sixpulse ripple in voltage will therefore occur in the rectifier (U_{b2} in figure 3). In order to isolate this voltage ripple from the DC-line a smoothing reactor (49) may be placed inside the DC filter (51).

When the thyristor valve G16 extinguish s and G12 is fired a closed current loop is formed on the rectifier side ver the diode valve D26, the valve windings B2 and C2 and diod valve D22. The current will only flow in this loop until the valve winding B2 has de-commutated the

current to winding C2. Then the diode valve D26 extinguishes. Thus the commutation is compl ted. Th turns ratio of the selfcommutated DC/DC power transformer $N_1 : N_2$ determines the relation between the bridge voltages of the rectifier and the inverter $U_{b1} : U_{b2}$ and the bridge currents $I_{b2} : I_{b1}$, where

N_1 - number of turns in the valve winding of the inverter (43) and

N_2 - number of turns in the valve winding of the rectifier (45).

The inverter side DC line current, I_{d1}, is determined by the average value of the bridge current

$$I_{d1} = I_{b1} / (1 - 3u_T/T).$$

The rectifier side DC line voltage, U_{d2}, is determined, by the average value of the bridge voltage

$$U_{d2} = U_{B2} (1 - 3u_T/T)).$$

The effective turn ratio of the DC/DC power transformer is therefore a function of the load $(-U_{d1} : U_{d2} = I_{d2} : I_{d1} = N_1 : N_2 (1 - 3u_T/T)$.

The principle for the firing and extinction of the line commutated DC/DC power transformer is illustrated in figures 5 and 6. A schematic circuit diagram for a six pulse group is given in figure 5, with the thyristor valves of the rectifier (T21 - T26), the valve winding of the rectifier (A2, B2, C2), the inverter thyristor valves (T11 - T16), the inverter valve windings (A1, B1, C1) and the windings to the AC voltage reference (A3, B3, C3). The letters in these designations determines the phase of respective winding.

The firing sequence of the sixpulse group of the line commutated DC/DC power transformer is shown in figure 6. The control pulses for the thyristor valves connected to the inverter are indicated by T11 ⇒ ...⇒ T16. The control pulses show the time interval when a valve shall be on and provided with firing pulses as soon as the blocking voltage becomes positive. The currents through the to the inverter in a star connected valve windings are denominated I_{A1}, I_{B1}, I_{C1}. The control pulses for the thyristor valves connected to the inverter are indicated by T21 ⇒ ... ⇒ T26. The current through the to the rectifier in delta connected valve windings are denominated I_{A2}, I_{B2}, I_{C2}. The differences between th se currents corrected with respect to turns ratio are the ampere turns diff r nc s which ach phase f th AC windings must compensate for. These AC currents denominated I_{A3}, I_{B3} and I_{C3} are shown in figure 6. The AC voltage refer nce currents may through

Fourier analysis be regarded as a summary of a fundamental component, phase shifted 90° el after the voltage and a number of harmonics. The fundamental current component in the AC reference net represents the reactive power which must be provided to the DC/DC power transformer. The harmonics are compensated by the AC-filters connected to the AC reference net.

The commutation process of the line commutated DC/DC power transformer is illustrated in figure 7. The AC voltage reference is exemplified by the phase voltage U_{A3}, which in the example in figure 5 is in phase with the phase voltage of the inverter U^{Y}_{A1}. The commutation from valve T12 to valve T14 is achieved by the commutation voltage U^{Y}_{A1C1}, which is the difference between the two phase voltages U^{Y}_{A1} and U^{Y}_{C1}. U^{Y}_{C1} is phase shifted 120° el before U^{Y}_{A1}, while $U^{Y}_{A1C1}(\omega t) = \hat{U}^{Y}_{A1}(\sin \omega t - \sin(\omega t + 2\pi/3)) = \sqrt{3}\,\hat{U}^{Y}_{A1}\sin(\omega t - \pi/6)$, i.e U^{Y}_{A1C1} is phase shifted 30° el after U^{Y}_{A1}. Commutation from thyristor valve T12 to valve T14 starts with firing of valve T14 at the instant when an angle $(\gamma + u)$ remains bef re the phase-to-phase voltage U^{Y}_{A1C1} becomes zero. The commutation voltage U^{Y}_{A1C1} commutes the direct current from valve winding C1 to valve winding A1 during the commutation interval "u". The DC-current through winding A1 is demonstrated as I^{Y}_{A1} in figure 7. The valve winding of the rectifier is in the example in figure 5 phase shifted 30° el. before the inverter by means of a Y_d11 coupling. The phase voltage U^{d}_{A2} is thus phaseshifted 30° el before the AC reference winding voltage. The phase-to-phase voltage U^{d}_{A2C2} comes 30° el after the phase voltage and is consequentially in phase with the AC reference winding voltage. The commutation from thyristor valve T25 to thyristor valve T21 in the inverter starts α degrees after zero passage of the phase-to-phase voltage U^{d}_{A2C2} and ends u degrees later. After commutation of the DC current to the valve T21 the DC current in the rectifier will pass through valve T26 and windings C2 in series with A2 parallel to the winding B2. During the time T21 and T26 conduct only a third of I_{d2} flows through winding A2. When the valve T26 commutes the current to the valve T22 the DC-current will pass through winding A2 parallel to windings C2 in series with B2. Th n the DC-current through winding A2 will increase to 2/3 I_d and so on in the way illustrated by current I^{d}_{A2} in figure 7. The current amplitude I^{d}_{A2} is expr ssed in per unit valve referred to the AC reference winding side and is therefore multified with factor $\sqrt{3}$ as turns ratio factor for delta connected windings.

The differential current, I_{A3}, between rectifier and inverter windings of phase A, is delivered to the AC reference winding. If the summary angle ($\alpha + \gamma + u$) is the same as the phase shift between these two, this current will have the smooth shape as in figure 6. Otherwise current peaks will occur in the way demonstrated by current I_{A3} $Y_d 11$ in figure 7. In order to minimize current harmonics it is therefore desirable to control the summary angle ($\alpha + \gamma + u$) against the same value as the phase shift between rectifier and inverter valve windings.

DESCRIPTION OF THE INVENTION

In figure 1 is shown the known high voltage DC transmission.

In figure 2 is shown the proposed arrangement of a 12 pulse line c mmutate DC/DC Power Transformer.

In figure 3 is illustrated the valve voltages and currents of a self commutated sixpulse DC/DC power Transformer.

In figure 4 is shown the circuit diagram of a sixpulse self commutated DC/DC Power Transformer.

In figure 5 is shown the circuit diagram of a sixpulse line commutated DC/DC Power Transformer.

In figure 6 is shown the firing and extinction sequence with valve currents of a 12 pulse line commutated DC/DC Power Transformer.

In figure 7 is shown the valve and winding currents and voltages of a 12 pulse line commutated DC/DC Power Transformer.

In figure 8 is shown the power control strategy of a line commutated DC/DC Power Transformer.

In figure 9 is shown a physical configuration of the valve windings in a three phase DC/DC Power Transformer.

In figure 10 is shown the circuit diagram of a 12 pulse line commutated auto DC/DC Transformer.

THE SELF COMMUTATED DC/DC POWER TRANSFORMER

The circuit diagram of a sixpulse selfcommutated DC/DC power transformer is shown in figure 4. As already mentioned a voltage ripple is created on the rectifier side due to the commutation process. In order to isolate this voltage ripple from the dc line a smoothing reactor (49) may be connected to the valve bridge and a dc filter (51) outside the smoothing reactor.

The dc-commutation with the diodes (D11-D16) on the inverter side generates a sixpulse ripple in the current (I_{b1} in figure 3), which

with a finite dc capacitor (48) will result in a certain voltage ripple also over this valv bridge. In order to r duce current and v ltage ripple the dc capacitor may be designed as a filter. If two sixpulsebridges (42) shifted 30° el between each other with respect to firing and extinction sequence are series connected the voltage ripple will be reduced and its frequency doubled. The remaining voltage harmonics are absorbed the smoothing reactors (49, 50).

The in fig. 4 demonstrated self commutated DC/DC power transformer can only transmit power from the inverter side to the rectifier side. If power transmission is desired in both directions the rectifier bridge (46) may be exchanged to another inverter bridge (42), provided with selfcommutated thyristors and antiparallel connected diodes, where the former are disactivated during rectifier operation. The power transmission direction is thereby determined by which of the two bridges is activated in inverter mood through forced firing and extinction sequence. The DC-filter (48) then ought to be connected to either sid of the smoothing reactor depending upon power flow direction. In principle the valves in the inverter are built up of selfcommutated thyrist rs (G11-G16) antiparallel connected diodes (D11-D16), which both for high voltages must be series connected and provided with common voltage divider elements and heat sinks.

A self commutated DC/DC Power Transformer built up according to the principle described here may have normal current control for dc lines as described in chapter 7 and reference 4. The current through the transformer is determined by the difference in voltage between power source net and power load net, and pulse frequency since these affect the transformer turns ratio $N_1 : N_2(1-3u_T/T)$. The control system of the transformer substation ought to be provided with protections against blocking by dc line fault and other short circuits creating harmful overcurrents and overvoltages.

LINE COMMUTATED DC/DC POWER TRANSFORMERS

The necessary commutation voltage for the line commutated valves is most easily provided by an AC voltage reference winding connected to each transformer unit and phas . The AC voltage referenc (36) generates a sinusoidal flow in the core. The rectifier and inverter bridges sets their delay angles in relation to this reference voltage.

In order to maintain the ampere turns balance in each transformer core (32, 33) the windings in the rectifier and inverter bridges are phase

shifted, so that the valve windings from respective rectifier and inverter bridges conduct as much as p ssible simultaneously. Then the best ampere turns balance is achieved. As a consequence of the firing, extinction and overlap angles the phase shift between rectifier and inverter can never be completily balanced out on a transformer core. A reactive power deficit occurs that must be compensated by the AC voltage reference winding (34, 35). The necessary reactive power can be supplied from a synchronous generator (36) or via thyristor- and/or breaker switched shunt capacitor banks. if necessary in combination with SVC control of known technology, described in chapter 10 of reference 4.

In the presently known thyristor valves the firing angle (α) in the rectifier is normally controlled between 5° and 20°. In the invert the extinction angle is normally kept over 17°. Normal values of the overlap angle are 10° - 15°. With these delay angles the summary angle ($\alpha + \gamma + u$) of the DC/DC Power Transformer would become between 30° and 60°. With improved firing and extinction characteristics the nominal value of the summary angle ($\alpha + u + \gamma$) should be possible to reduce. In the example in figure 2 a phase shift between rectifier and inverter of 30° has been chosen. This is achieved by couplings Yd11 and Dy11 according to SEN 270101. In order to achieve greater phase shifts the valve windings of either one or both sides can be connected in a Z-coupling or with extended delta.

By series connection of sixpulse bridges in the rectifier and inverter phase shifted in relation to each other and to the AC windings the current harmonics are reduced in the same manner as for the known 12 pulse converter (see reference 1 chapter 8.2), which reduces necessity for harmonic AC-filters (39). The phase and phase-to-phase voltages and different phase A transformer winding currents of the line commutated DC/DC power transformer in figure 2 are shown in figure 7. In this example following delay angles have been chosen $\alpha = 10°$, $\gamma = 15°$ and $u = 10°$.

The valve winding currents of the sixpulse group with Yd11 coupling are denominated I_{A2}^{d} in the rectifier and I_{A1}^{Y} in the inverter. Corresponding AC reference winding current, I_{A3}^{Yd11}, equals the difference between these currents. The valve winding currents of the oth r Dy11-coupled sixpulse group are in the rectifi r denominated I_{A2}^{Y} and in the inverter I_{A1}^{D} and is deduced in the same manner as for th first

sixpulse group. The difference between these currents, I_{A3}^{Dy11}, is the corresponding AC reference winding current. The summary f I_{A3}^{Yd11} and I_{A3}^{Dy11} is the total phase current, I_{A3}^{tot}, which the AC reference winding shall supply to the DC/DC power transformer. The fundamental component of this current is the reactive power current of the DC/DC power transformer phaseshifted 90° el after the voltage. The spikes in this current is due to that the summary angle (α + γ + u) in this case (−35°) deviates from the phaseshift between rectifier and inverter (−30°). In order to achieve a greater phaseshift between the valve windings of the rectifier and inverter, the rectifier windings can be connected into a "Z" or to an extended delta phase shifter x° el before the AC reference winding. The phaseshift x can be designed freely between 0° and 30°, through choice of number of turns between the d lta and star part of the extended delta. The inverter valve winding can at the same time be connected to a delta, phaseshifted 30° el after the AC reference winding. In this manner any desired phaseshift between 30° el 60° el can be obtained. The phaseshift between the two in all ther respect equal series connected sixpulse groups can be obtained by starconnection of one of the AC reference windings and delta connection of the other. This procedure is demonstrated for the autocoupled DC/DC power transformer in figure 10. The phaseshift between rectifier and inverter should, in order to minimize the current harmonics, be chosen so that it coincides with normal stationary operational value of the summary angle (α + γ + u). The control of the line commutated DC/DC power transformer may also be adjusted for control against nominal value of the summary angle. The control system of high voltage DC transmission is known and described in chapter 7 of reference 4. For a DC/DC power transformer with line commutated valves certain additional control parameters are to be considered due to the influence of the AC voltage reference net. Figure 8 illustrates schematically the power control of the line commutated DC/DC power transformer (54). The current control of each converter is performed in the known manner. The coordination between the different current orders and the voltage of the AC voltage reference net assures that balanc is maintained between incoming (P_{in}) and outgoing (P_{ut}) active power. Th balance between the consumtion of reactive power (Q) and the generation of reactive power (Qg) provided by AC voltage reference net is controlled by the reactive power control (53).

The power order (52) is set in on of the stations, for example in the rectifier of the supplying dc-network. From here current orders to th entire dc-net are emitted. The pow r change may not be faster that what the reactive power control of the DC/DC power transformer permits. The current order between supplying net (I_{orderR}) and the supplied net (I_{orderI}) and the inverter of the DC/DC power transformer (I_{order1}) and its rectifier (I_{order2}) are coordinated. Normally current orders are set so that inverters control the voltage, while the rectifiers control the current. Increased stability on the AC voltage reference net is achieved if also the current control (55) in the inverter of the supplied ac-network is allowed to control the current (I_{d2}) in the supplied dc-net.

The different windings in the DC/DC power transformer (28-31, 34-35) may all be placed in one and the same transformer unit. In its most compact form, which probably only is applicable on lower powers, all windings are placed in one transformer unit. In figure 9 such a threephase threewinding transformer is shown, for example for windings 30, 31, 35 and core 33 in figure 2. Each transformer core leg (56, 57, 58) has in this transformer been provided with three windings from the same phase. The innermost windings (59A, 59B, 59C) are in this case th three phases (A, B, C) of the AC reference winding (34). The intermediate windings (60A, 60B, 60C) are in this case the three phases of the inverter valve windings (30) connected into a star. The outmost windings (61A, 61B, 61C) are the three phases of the rectifier valve windings (31), closed in a delta.

The smallest power per unit, which also means the highest number of separate units, is achieved if only one valve winding belonging to each bridges (25 resp 26) and one AC-winding (34, 35) are placed into one unit. The AC voltage reference net (36) then interconnects the different AC windings of each transformer unit for each phase.

AUTO COUPLED DC/DC POWER TRANSFORMER

In reference 2 a form of series and parallel connection of inverters and rectifiers are shown which is called "D.C. voltage transformation in high tension systems".

A rectifier (62) and an inverter (63) are c nnected in opposite directions in a DC voltage transformation point so that the power is transformed from one DC voltage level (U_{d1}) to an ther DC voltage level (U_{d2}) without sectionizing power. If the valve windings of the

rectifier (64, 65) and of the inverter (66, 67) in this combined bridges are connected to the same transformer core (68, 69) an aut coupled DC/DC power transformer is achieved as shown in figure 10. Th rectifier bridge (62) is here cascade connected to the inverter bridge (63). With this autocoupling the high voltage valve bridge only needs to be voltage wise designed for the difference in voltage (U_{d2} - U_{d1}) and the low voltage valve bridge only needs to be current wise designed for the difference in current (I_{d1} - I_{d2}). The result is that less costly equipment is needed, lower losses are generated as well as less reactive power is consumed as compared with basic concept.
In example in figure 10 is shown how the rectifier valve windings (64, 65) are phaseshifted 45° before the inverter valve windings (66, 67) and how at the same time 30° phaseshift is achieved between the two AC reference windings (71, 71).
The auto coupling is of course also suitable for DC/DC power transformer with self commutated valves.

References

Ref. 1 E.W. Kimbark "Direct Current Transmission", Volume I, 1971 by John Wiley & Sons.

Ref. 2 Kanngiesser US Patens 3 942 089 may 1976 "DC Voltage Transformation in High Tension Systems".

Ref. 3 K. Thorborg "Power Electronics", 1988, Prentice-Hall International (UK) Ltd.

Ref. 4 Å. Ekström "Kompendium i Högeffektelektronik", KTH/EKC jan 1988.

PATENT CLAIMS

1. An arrangement for transformation of high electric p wers from one DC voltage level (U_{d1}) to another DC voltage level (U_{d2}) by means of transformers provided with valve windings (28 - 31) connected to valve bridges with several parallel bridgearms (A, B, C). The valves are fired and extinguished in a cyclic sequence, so that the current cyclically commutates from one valve winding to another and a cyclically variating magnetic field is created in the transformer cores (32, 33)
c h a r a c t e r i z e d b y,
that one of the valve bridges works as a rectifier (26) and the other valve bridge works as an inverter (24), and around one and the same transformer core is wound valve windings from the rectifier as well as the inverter with opposing magnetic fields in the transformer core and that the magnetic energy stored by the transformer core commutates from a transformer winding of one bridge arm to another according to a cyclic sequence.

2. An arrangement according to claim 1,
c h a r a c t e r i z e d b y,
that the rectifier bridge and the inverter bridge are connected in cascade; over the high voltage valve bridge the difference between the DC voltages is applied ($/U_{d1} - U_{d2}/$) and through this valve bridge with its valve windings passes the DC current of the higher potential; over the low voltage valve bridge the DC voltage with lower potential is applied and through this valve bridge and respective valve windings passes only the difference in current between rectifier and invert r ($/I_{d2} - I_{d1}/$).

3. An arrangement according to claim 1,
c h a r a c t e r i z e d b y,
that around one and the same transformer core the rectifier and inverter valve windings are phase shifted so that the ampere turn ratio between these to windings is to the greatest possible extent balanced under as much as possible of the conduction interval.

4. Arrangement according to claim 3, intended for valve bridges with line commutated valves,
c h a r a c t e r i z e d b y,
that apart from valve windings from both rectifier and inverter ar und each transformer core (32, 33), an AC-voltage ref rence winding (34, 35) is als provided in order to generate the n cessary commutation

voltage for commutation of the current from winding of one phase to another. This is achieved since the valves in both valve bridges are fired an extinguished with specified delay angles. The valve windings from the rectifier bridge (26) and inverter bridge (24) respectively are phase shifted in relation to the AC voltage reference winding through external connections in known star, delta, extended delta or other connections, so that best possible ampere turns balance is achieved between rectifier and inverter valve windings.

5. Arrangement according to claim 1,
c h a r a c t e r i z e d b y,
that the cyclically variating magnetic field in the transformer core is created by that transformer windings (43) connected to a valve bridge with self commutated thyristor valves (42) is connected to a DC voltage source (U_{d1} in figure 4). The self commutated thyristor valves in the valve bridge are fired and extinguished in a predetermined cyclic sequence, so that said variating magnetic field is created and the hereby stored magnetic energy is commutated from one winding to another via an external capacitor (48). In other valve bridge (46) with the valve windings magnetically coupled to the same transformer core (44) as above, the voltages and currents induced into these windings (45) are now rectified so that the electric energy is transformed into another DC voltage (U_{d2} in figure 4).

6. Arrangement according to claim 5,
c h a r a c t e r i z e d b y,
that the valve bridge connected to the DC-voltage source is made up of one (or several) 6-pulse inverter bridge (42) with cyclically extinguished and fired (fig. 3) self commutated thyristors (G11 - G16) with diodes (D11 - D16) connected antiparallel to these thyristors. Both thyristors and diods can be seriesconnected into valves. The other valve bridge is a 6-pulse rectifier bridge (46) built up of diode valves (D21 - D26).

7. Arrangement according to claim 6,
c h a r a c t e r i z e d b y,
that the inverter valves is built up with a common voltage divided and common cooling for both thyristors and diodes.

8. Arrangement according to claim 5,
c h a r a c t r i z e d b y,
that both valve bridges are built as inverter bridges (42), that is composed of selfcommutated thyristors in antiparallel to diodes (D11 - D16) series connected in the same valve or not. The power flow is determined by how and in which valve bridge the cyclic firing and x-tinction sequence is applied.

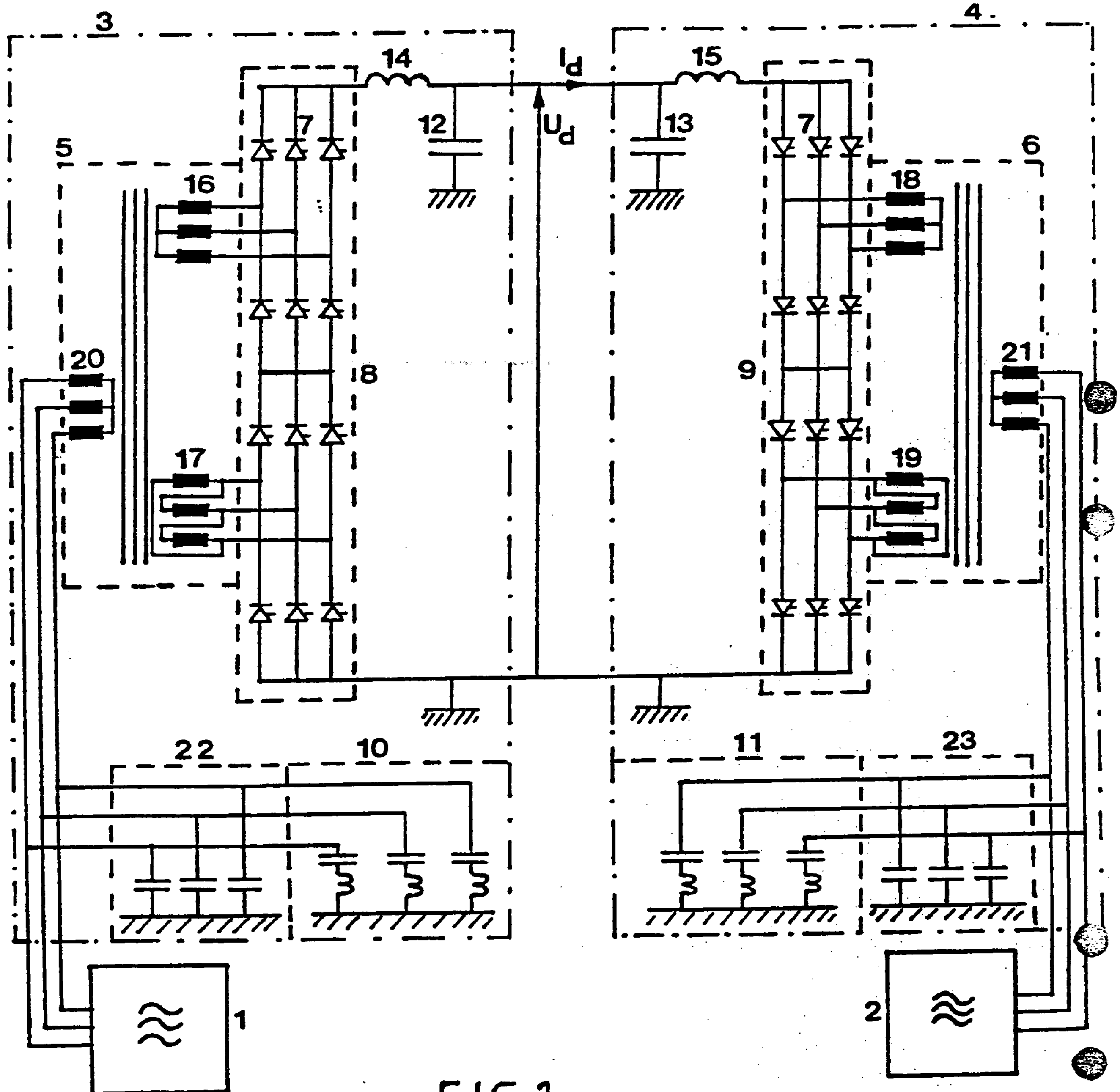

FIG 1

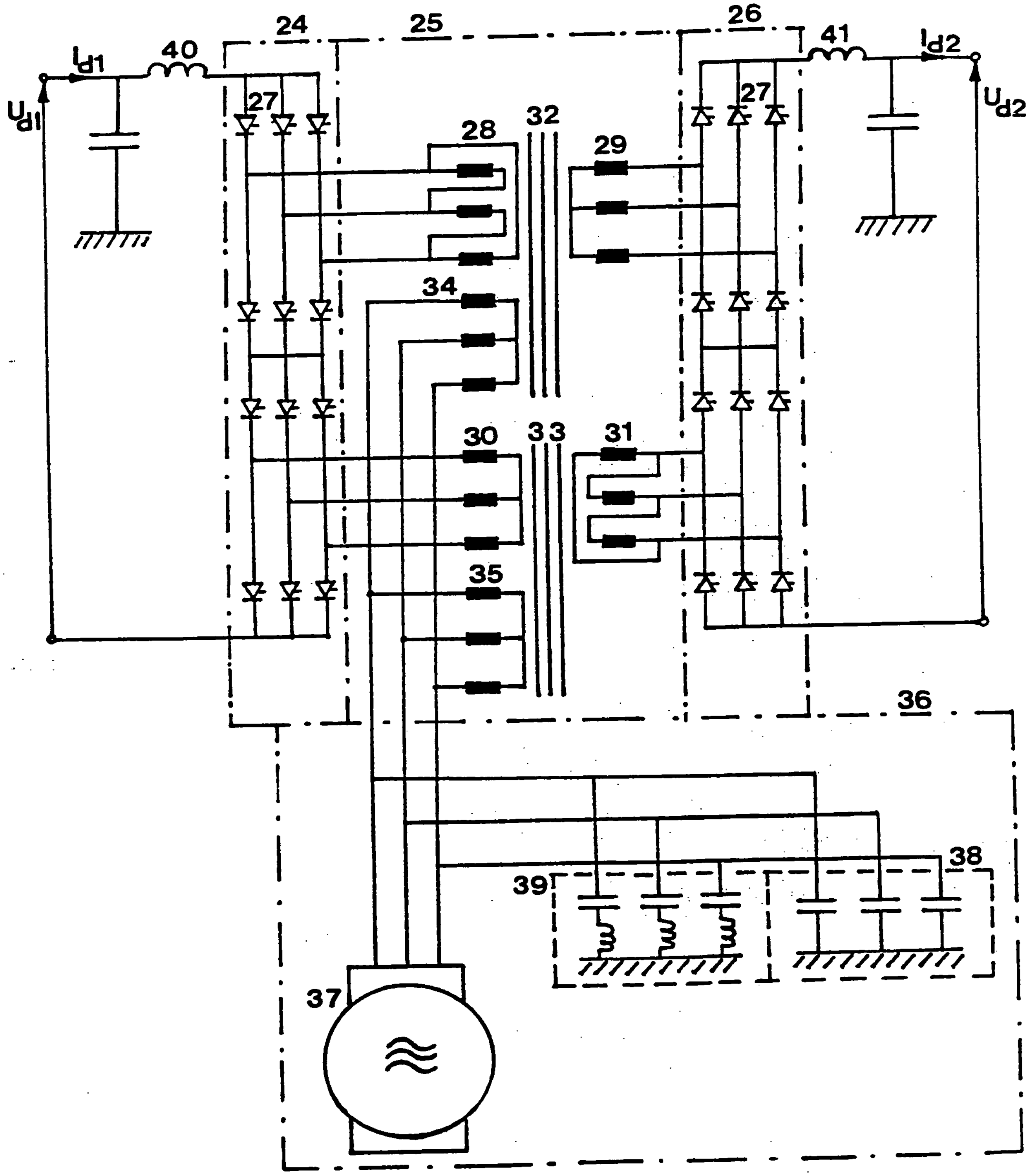
24
25
26
I_{d1}
40
41
I_{d2}
U_{d1}
U_{d2}
27
27
28
32
29
34
30
33
31
35
36
38
39
37

FIG 2

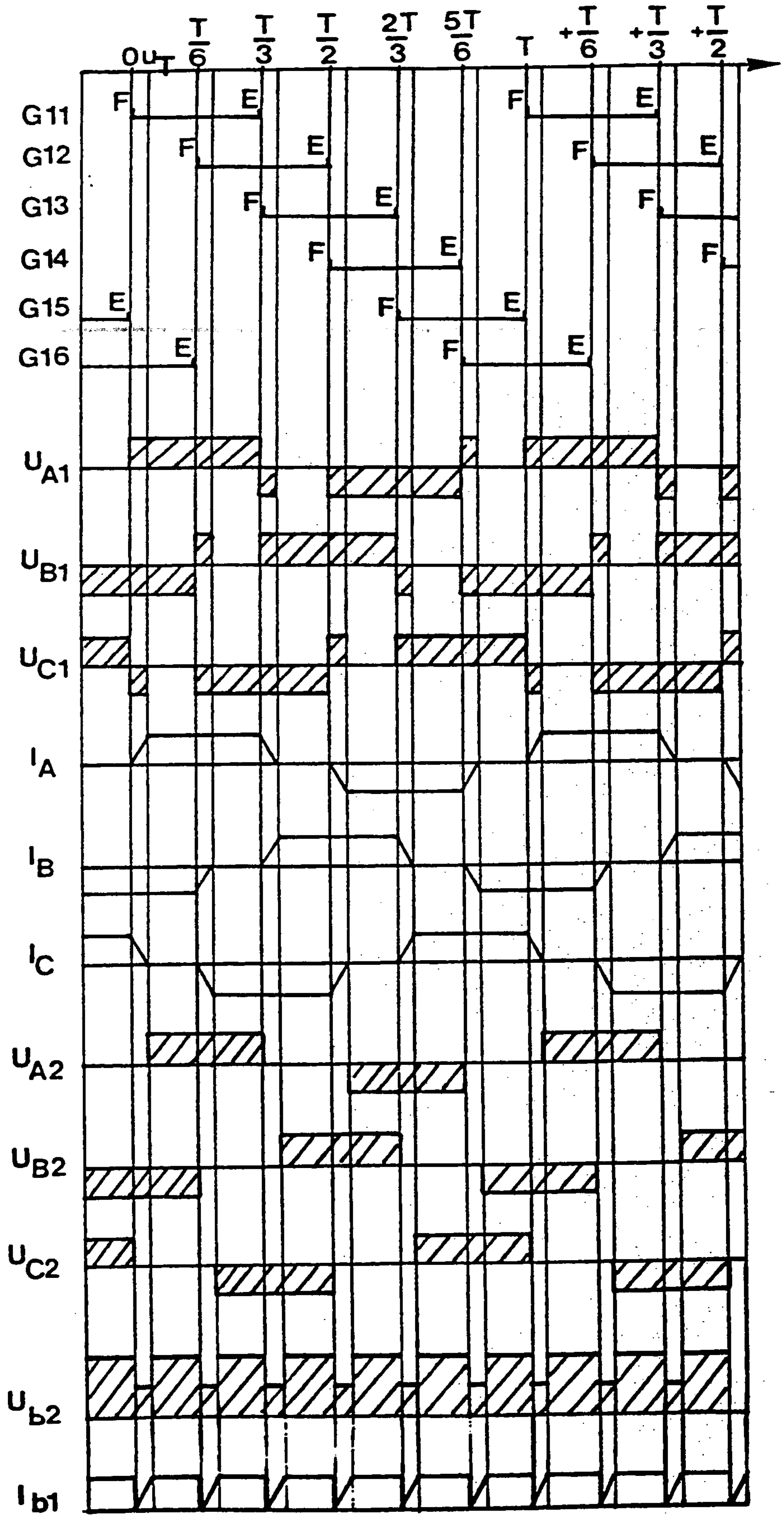
0
u
T
T/6
T/3
T/2
2T/3
5T/6
T
+T/6
+T/3
+T/2
G11
G12
G13
G14
G15
G16
F
E
U_{A1}
U_{B1}
U_{C1}
I_A
I_B
I_C
U_{A2}
U_{B2}
U_{C2}
U_{b2}
I_{b1}

FIG 3

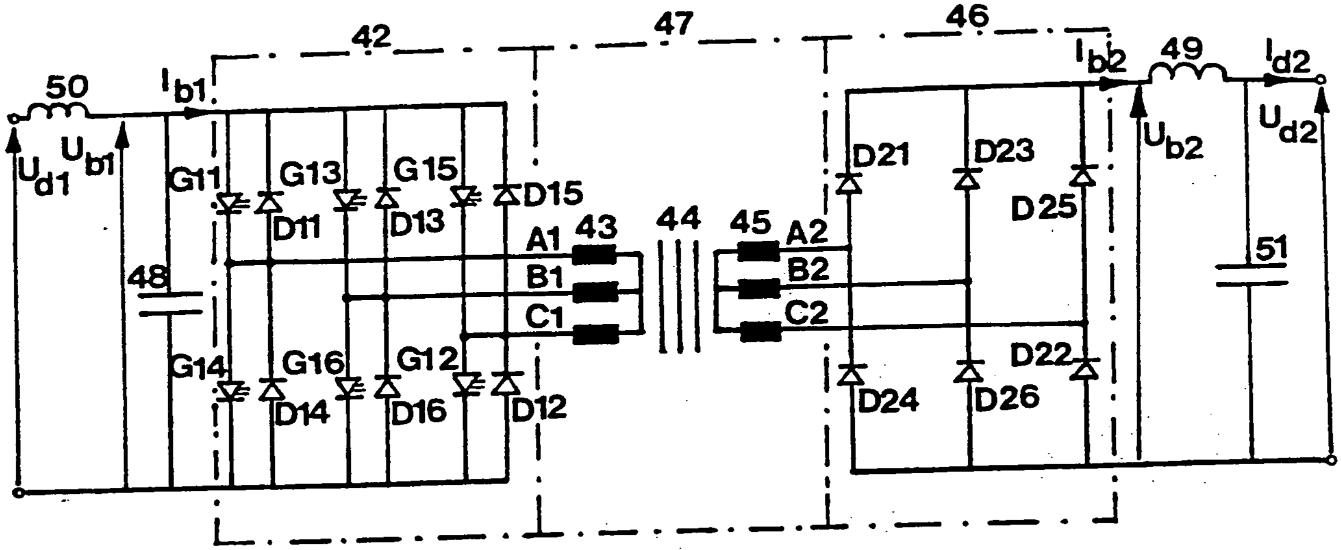
42
47
46
50
I_{b1}
I_{b2}
49
I_{d2}
U_{d1}
U_{b1}
U_{b2}
U_{d2}
G11
G13
G15
D15
D11
D13
A1
43
44
45
A2
B1
B2
C1
C2
48
G14
G16
G12
D14
D16
D12
D21
D23
D25
51
D22
D24
D26

FIG 4

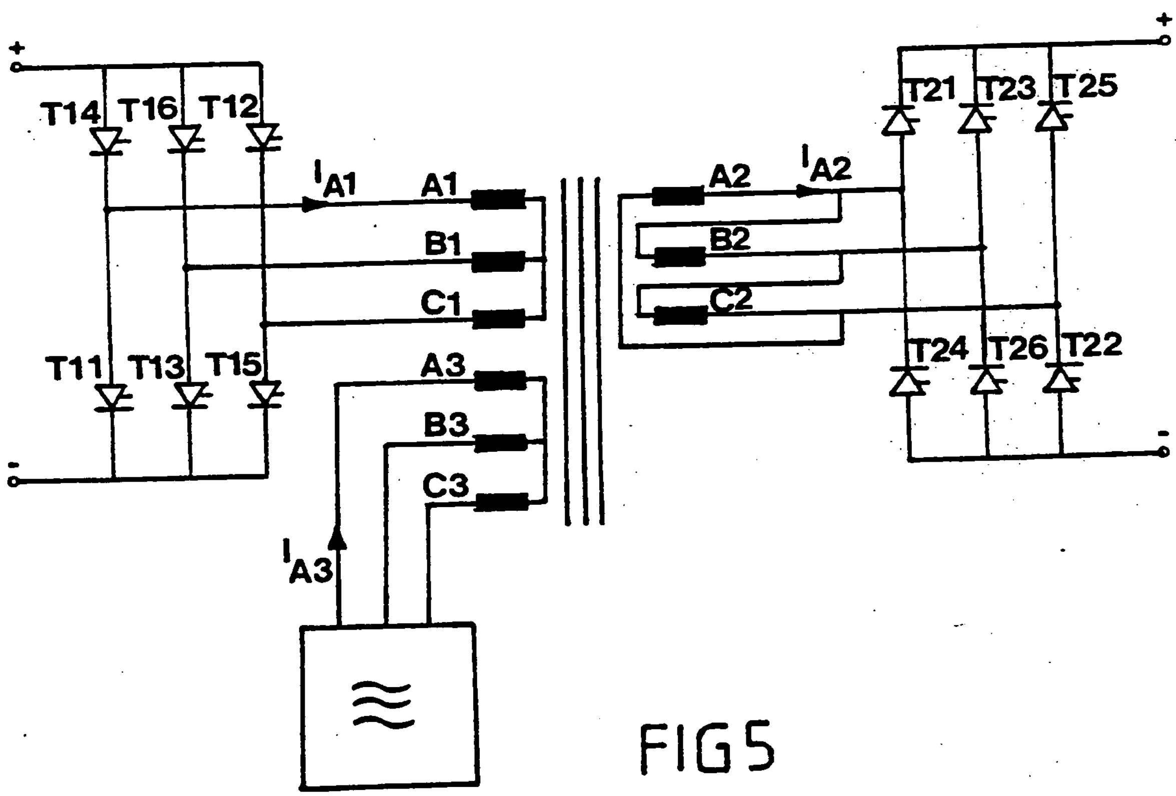
+
T14
T16
T12
I_{A1}
A1
B1
C1
T11
T13
T15
A3
B3
C3
-
I_{A3}
A2
I_{A2}
B2
C2
+
T21
T23
T25
T24
T26
T22
-

FIG5

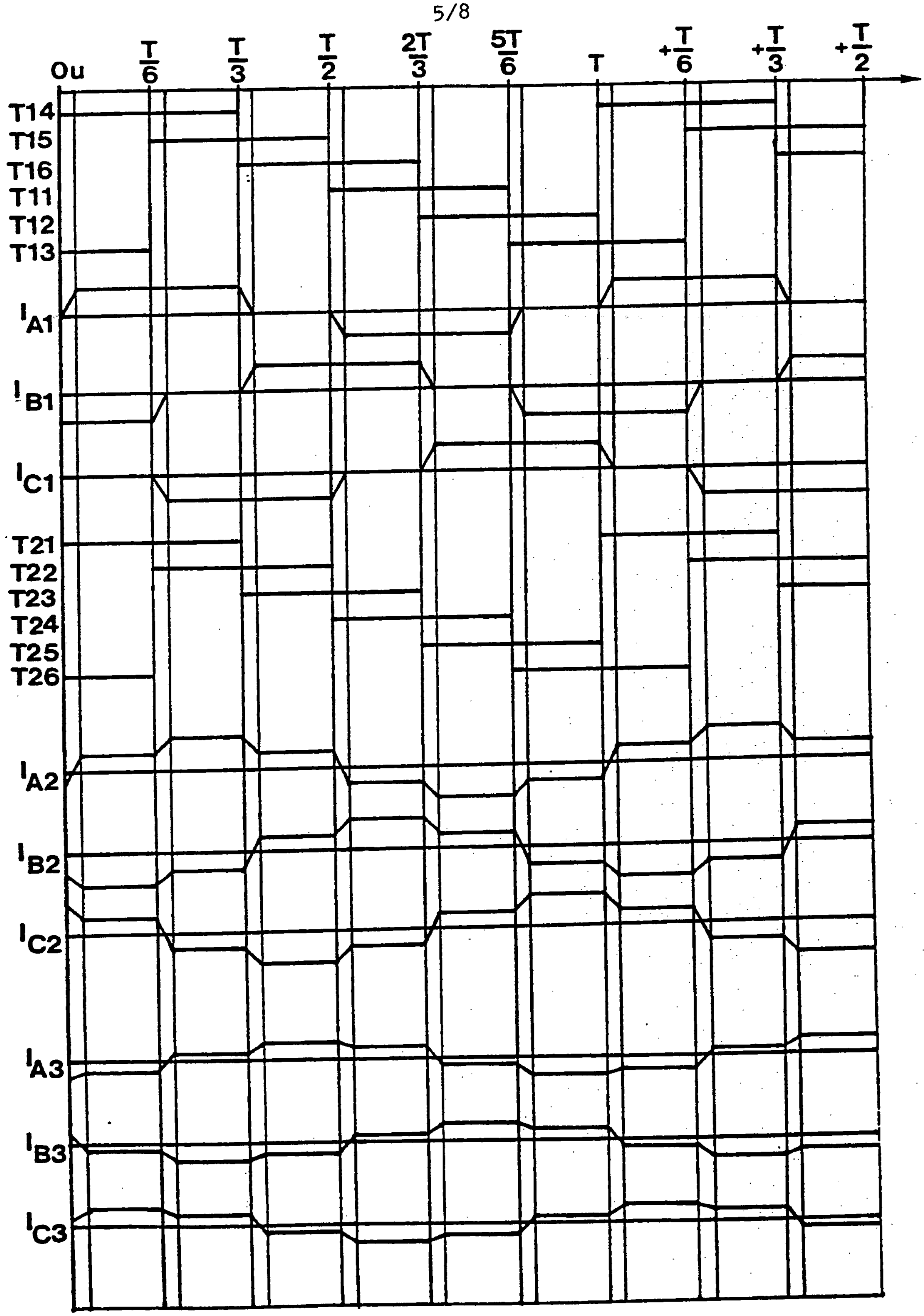
Ou
T/6
T/3
T/2
2T/3
5T/6
T
+T/6
+T/3
+T/2
T14
T15
T16
T11
T12
T13
IA1
IB1
IC1
T21
T22
T23
T24
T25
T26
IA2
IB2
IC2
IA3
IB3
IC3

FIG 6

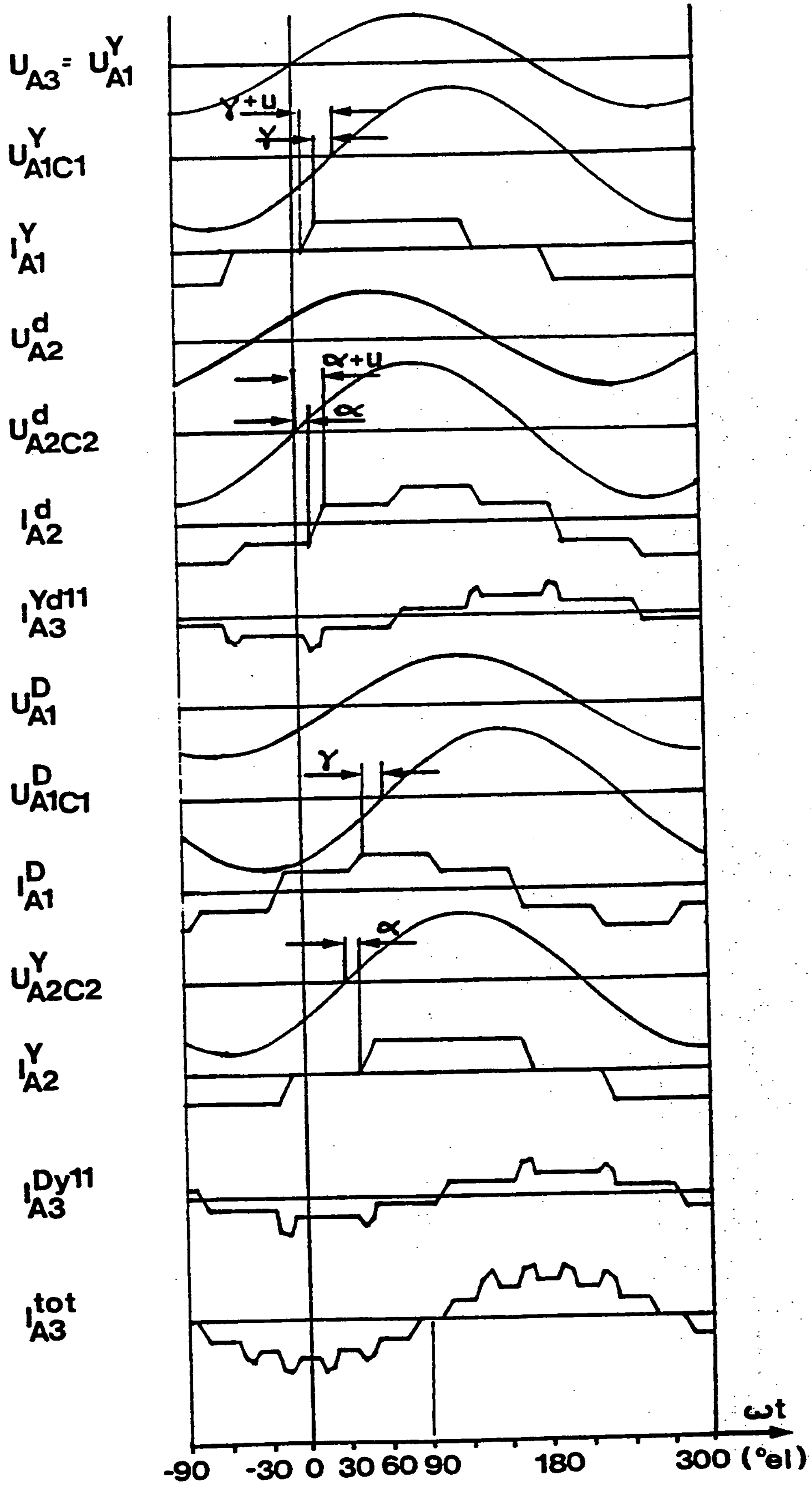
$U_{A3} = U^{Y}_{A1}$
γ+u
γ
U^{Y}_{A1C1}
I^{Y}_{A1}
U^{d}_{A2}
α+u
α
U^{d}_{A2C2}
I^{d}_{A2}
I^{Yd11}_{A3}
U^{D}_{A1}
γ
U^{D}_{A1C1}
I^{D}_{A1}
α
U^{Y}_{A2C2}
I^{Y}_{A2}
I^{Dy11}_{A3}
I^{tot}_{A3}
ωt
-90
-30
0
30
60
90
180
300 (°el)

FIG 7

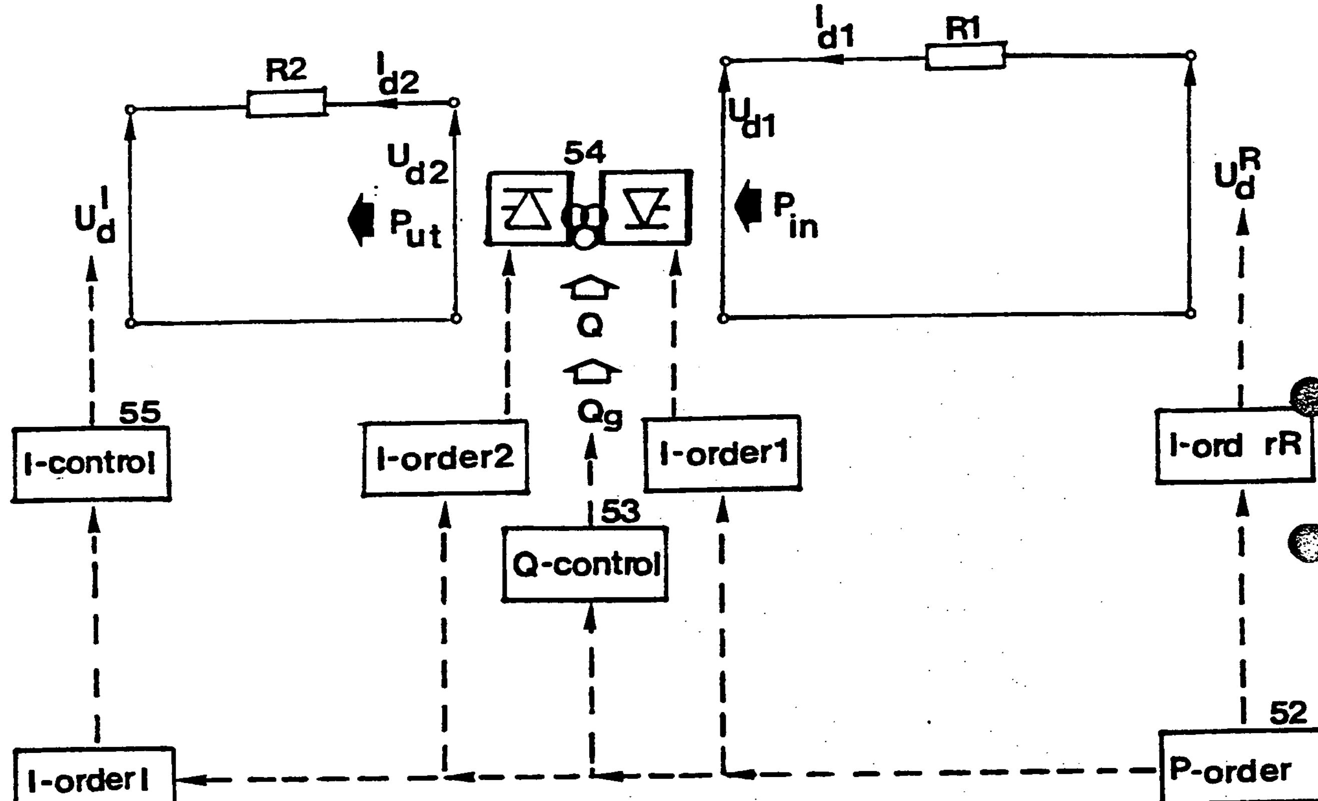
R2
I_{d2}
R1
I_{d1}
U_{d2}
U_{d1}
U_d^I
U_d^R
54
P_{ut}
P_{in}
Q
Q_g
55
I-control
I-order2
I-order1
I-ord rR
53
Q-control
52
I-order I
P-order

FIG8

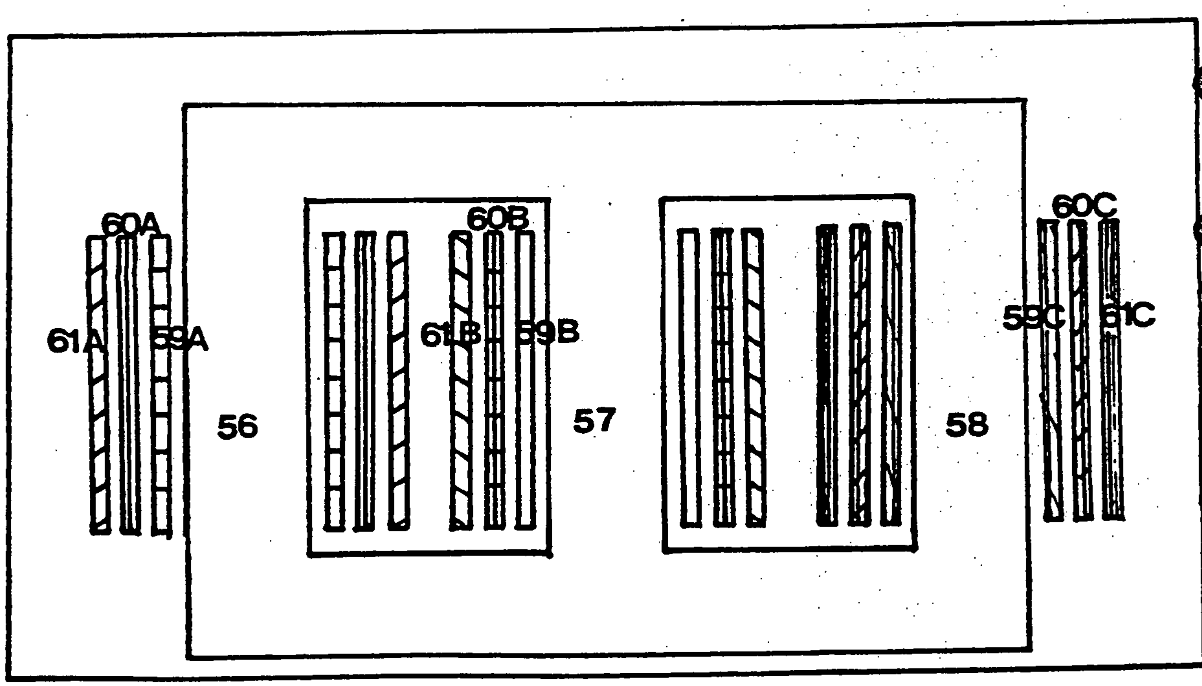
60A
61A
59A
60B
61B
59B
60C
59C
61C
56
57
58

FIG9

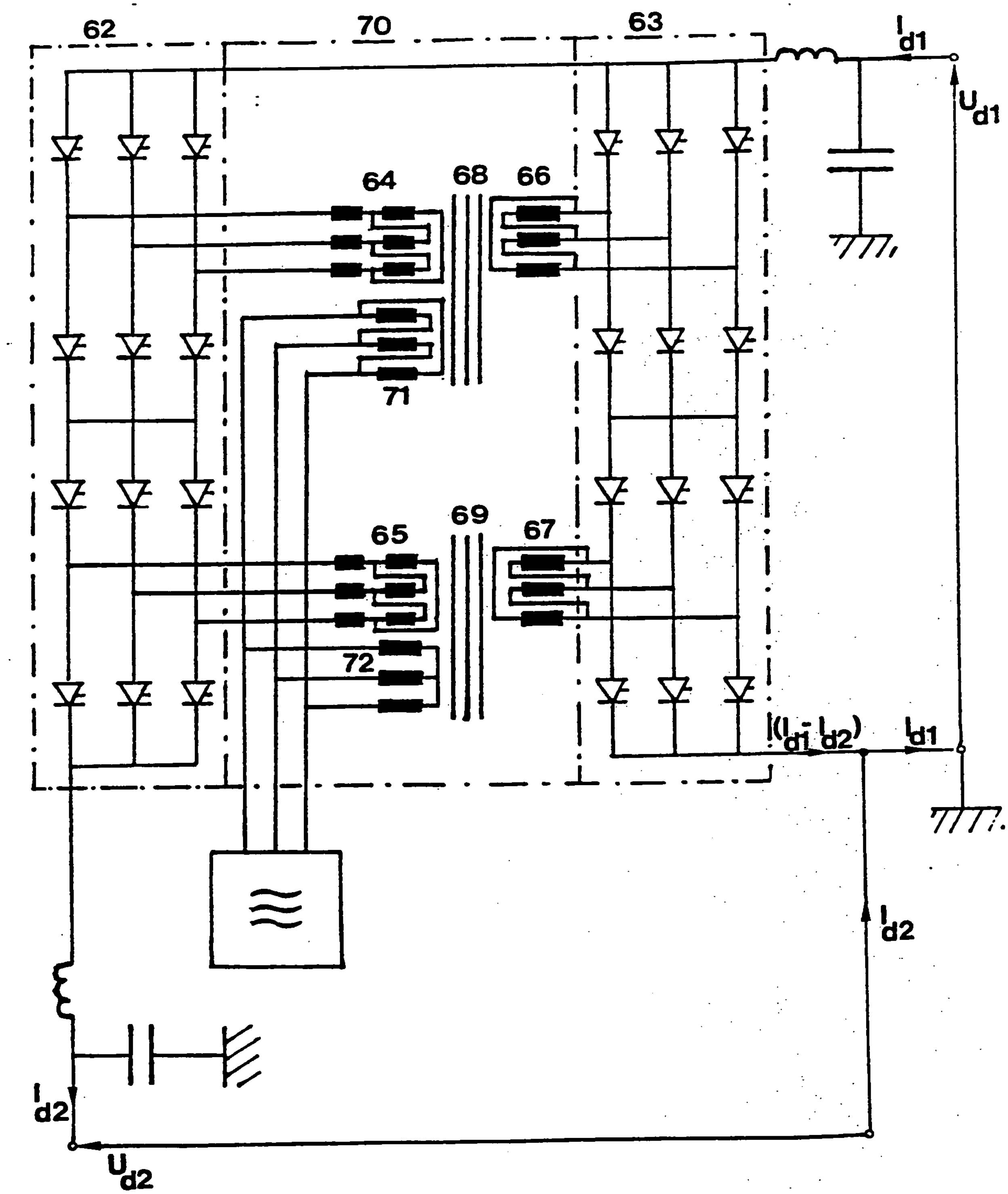

FIG 10

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 90/00710

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: H 02 M 3/22

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	H 02 M

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages[12]	Relevant to Claim No.[13]
A	Derwent's abstract, No. 84-299 373/48, SU 1 083 310, publ. week 8448 --	1-8
A	US, A, 3942089 (KANNGEISSER) 2 March 1976, see column 2, line 16 - column 4, line 33 --	1-8

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* Special categories of cited documents:[10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
6th February 1991	1991 -02- 12
International Searching Authority	**Signature of Authorized Officer**
SWEDISH PATENT OFFICE	HAKAN SANDH

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/SE 90/00710

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the Swedish Patent Office EDP file on 90-12-28
The Swedish Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 3942089	76-03-02	CA-A- 1029805	78-04-18
		CH-A- 582965	76-12-15
		DE-A-C- 2350778	75-04-24
		FR-A-B- 2247837	75-05-09
		GB-A- 1477026	77-06-22
		SE-B-C- 395801	77-08-22
		SE-A- 7412674	75-04-11